23rd Australasian Conference on the Mechanics of Structures and Materials

2014

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Publication details

Bahadori, A 2014, 'Estimation of soil particles size in hydrometer analysis test using a simple correlation', in ST Smith (ed.), *23rd Australasian Conference on the Mechanics of Structures and Materials (ACMSM23)*, vol. II, Byron Bay, NSW, 9-12 December, Southern Cross University, Lismore, NSW, pp. 757-761. ISBN: 9780994152008.

ESTIMATION OF SOIL PARTICLES SIZE IN HYDROMETER ANALYSIS TEST USING A SIMPLE CORRELATION

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ABSTRACT

Soil consists of an assembly of ultimate particles of various shapes and sizes. Hydrometer Analysis is based on the principle of sedimentation of soil grain in water. It is usually performed if the grain sizes are too small for sieve analysis. The method is based on Stoke’s law governing the rate of sedimentation of particles suspended in water. In this article a simple predictive tool is developed to estimate diameter of soil particles as a function of specific gravity of soil solids and temperature. Estimations are found to be in excellent agreement with reported data. The tool developed in this study can be of immense practical value for geotechnical engineers to have a quick check of diameter of soil grain for various soils at wide range of conditions without opting for any experimental trials. In particular, soil mechanics practitioners and civil engineers would find the proposed approach to be user-friendly with transparent calculations involving no complex expressions.

KEYWORDS

Hydrometer, soil grain, soil mechanics, Stoke’s law, predictive tool.

INTRODUCTION

Soil Hydrometer experiment measures the percentage of sand, silt and clay in the inorganic fraction of soil (Yong and Warkentin, 1966). When a soil specimen is dispersed in water, the particles settle at different velocities depending on their shape, size, weight and the viscosity of water.

The grain diameter thus can be calculated from knowledge of the distance and time of fall. The hydrometer also determines the specific gravity (or density) of the suspension, and this enables the percentage of particles of a certain equivalent particle diameter to be calculated (Das and Sobhan, 2014).

In the laboratory, the hydrometer test is conducted in a sedimentation cylinder usually with oven dried sample, sedimentation cylinder, a dispersing agent. The volume of the dispersed soil suspension is increased by adding distilled water (Das and Sobhan, 2014).

A hydrometer is then placed in the sedimentation cylinder. When a hydrometer is placed in the soil suspension at time t, it measures the specific gravity in the vicinity of its bulb at a depth L. Hydrometers are designed to give the amount of soil, in gram that is still in suspension. They are calibrated for soils that have a specific gravity of 2.65, for soils of other specific gravities a correction must be made (Das and Sobhan, 2014).

By knowing the amount of soil in suspension, L and t, we can calculate the percentage of soil by weight finer than a given diameter.

Usually for simplicity, it is assumed that all the soil particles are spheres and that the velocity of soil particles can be expressed by Stoke's law according to which (Das and Sobhan, 2014);

$$v = \frac{\rho_s - \rho_w}{18\eta} D^2 \tag{1}$$

Where:
v=Velocity,
D=diameter of solid particle
$\rho_s = density\ of\ soil\ particles$
$\rho_w = density\ of\ water$
$\eta = viscosity$
Thus from equation 1,

$$\text{D=}\sqrt{\frac{18\eta v}{\rho_s - \rho_w}} = \sqrt{\frac{18\eta}{\rho_s - \rho_w}}\sqrt{\frac{L}{t}} \tag{2}$$

Where v= Distance/time=L/t
Note that $\rho_s = G_s \rho_w$

Thus combining equation 1 and 2 gives:

$$D = \sqrt{\frac{30\eta}{(G_s - 1)\rho_w}} \times \sqrt{\frac{L}{T}} \tag{3}$$

So that:

$$D(mm) = K\sqrt{\frac{L(cm)}{t(\min)}} \tag{4}$$

$$K = \sqrt{\frac{30\eta}{(G_s - 1)}} \tag{5}$$

In view of the above, because viscosity of water is only a function of temperature, so it is necessary to develop an accurate and simple correlation which is easier than existing approaches, less complicated and with fewer computations to predict K value as a function of temperature and soil solid specific gravity. This paper discusses the formulation of such a predictive tool in a systematic manner.

DEVELOPMENT OF CORRELATION

The required data to develop this correlation includes the reported K-Value in equation 5 (Das and Sobhan, 2014) as a function of soil specific gravity and temperature. The following methodology has been applied to develop this correlation. Firstly K-Value data are correlated as a function of temperature at various soil specific gravities, then, the calculated coefficients for these equations are correlated as a function of temperature. The derived equations are applied to calculate new coefficients for equation (6) to predict K-Value.

Table 1 shows the tuned coefficients for equations (7) to (10) to predict K-Value in equation 5. In brief, the following steps are repeated to tune the correlation's coefficients using a Matlab program (2008) (Bahadori et al, 2009; Bahadori and Vuthaluru, 2010):

1. Correlate K-Value data as a function of temperature for a given soil specific gravity.
2. Repeat step 1 for other soil specific gravity values.
3. Correlate corresponding polynomial coefficients, which were obtained for different soil specific gravities versus soil specific gravity, a= f (sg), b = f (sg), c = f (sg), d = f (sg) [see equations (7)-(10)].

Equation 6 represents the proposed governing equation in which four coefficients are used to correlate K-Value data as a function of soil specific gravity and temperature, where the relevant coefficients have been reported in Table 1.

$$\ln(K) = a + bT + cT^2 + dT^3 \tag{6}$$

$$a = A_1 + B_1Sg + C_1Sg^2 + D_1Sg^3 \tag{7}$$

$$b = A_2 + B_2Sg + C_2Sg^2 + D_2Sg^3 \tag{8}$$

$$c = A_3 + B_3Sg + C_3Sg^2 + D_3Sg^3 \tag{9}$$

$$d = A_4 + B_4Sg + C_4Sg^2 + D_4Sg^3 \tag{10}$$

Where:
A: Tuned parameter
B: Tuned parameter
C: Tune Parameter
D: Tuned parameter
T: Temperature (℃)
Sg: Specific gravity

These optimum tuned coefficients help to cover temperature up to 30℃ and soil specific gravity between 2.45 and 2.80.The optimum tuned coefficients given in Table 1 can be further retuned quickly according to proposed approach if more data become available in the future.

In this work, our efforts directed at formulating a correlation which can be expected to assist soil mechanics and geotechnical engineers for rapid calculation of K-Value in equation 5 as a function of specific gravity and temperature using a simple correlation. The proposed novel tool developed in the present work is simple and unique expression which is non-existent in the literature. Furthermore, the selected exponential function to develop the tool leads to well-behaved (i.e. smooth and non-oscillatory) equations enabling reliable and more accurate predictions.

Table 1. Tuned coefficients used in Equations 7-10

Coefficient	Value
A_1	$-7.407239164462\times10^{2}$
B_1	$8.258339039198\times10^{2}$
C_1	$-3.081668154313\times10^{2}$
D_1	$3.828012060948\times10^{1}$
A_2	$9.144642660807\times10^{1}$
B_2	$-1.023440230930\times10^{2}$
C_2	$3.813440387849\times10^{1}$
D_2	-4.731586187944
A_3	-3.704535181083
B_3	4.141625197522
C_3	-1.541744886007
D_3	$1.91104489523\times10^{-1}$
A_4	$4.91664747629\times10^{-2}$
B_4	$4.91664747629\times10^{-2}$
C_4	$2.04174084222\times10^{-2}$
D_4	$-2.52787729313\times10^{-3}$

RESULTS

Figure 1 shows the proposed method results in comparison with data (Das and Sobhan, 2014). Figure 2 shows the results from the proposed method and its smooth performance in the prediction of K-value as a function of soil specific gravity and temperature. The deviation of correlation in terms of average absolute deviation is less than 0.5%. It is expected that our efforts in formulating a simple tool will pave the way for arriving at an accurate prediction of soil particle size which can be used by soil mechanics practitioners and civil engineers for monitoring the key parameters periodically.

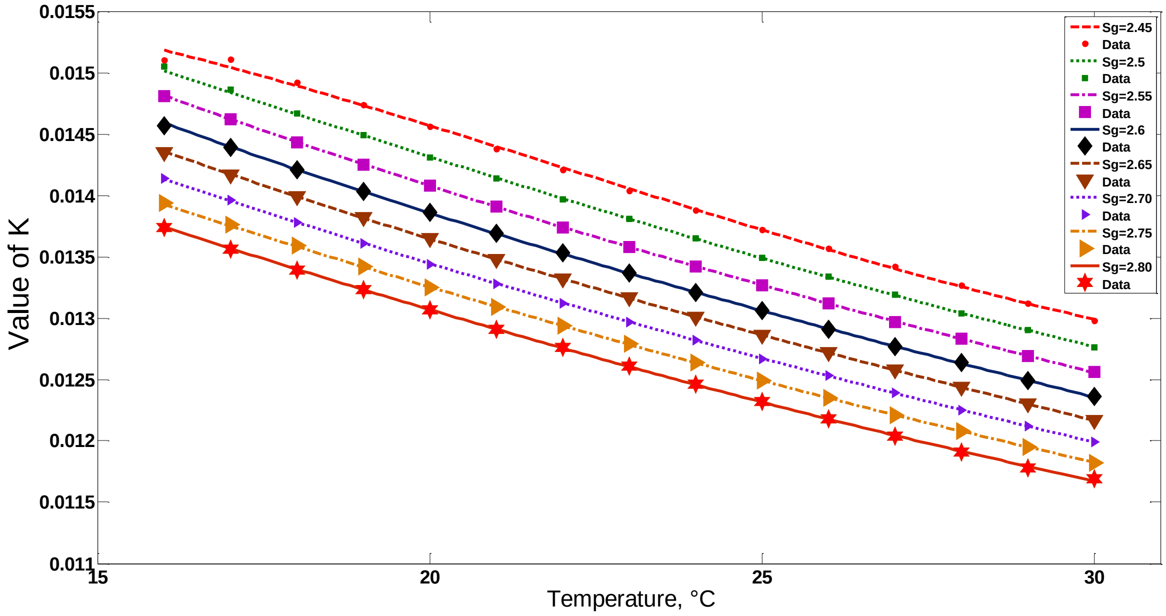

Figure 1. The performance of predictive tool in comparison with data (Das and Sobhan, 2014) for calculating K-value in equation 5.

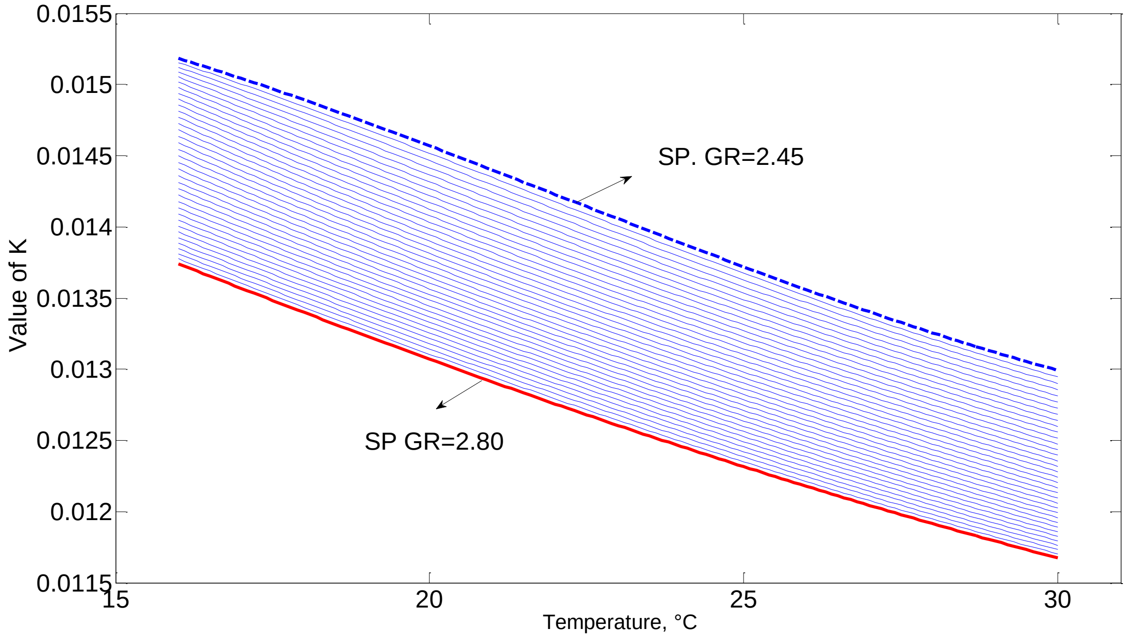

Figure 2. The smoothness of results of predictive tool for the estimation of K-value in equation 5

CONCLUSIONS

In this work, simple-to-use equations, which are easier than existing approaches less complicated with fewer computations and suitable for civil engineers is presented here for the estimation of soil particle size as a function of soil specific gravity and temperature.

Unlike complex mathematical approaches for estimating soil particle size, the proposed correlation is simple-to-use and would be of immense help for civil engineers especially those dealing with soil mechanics experiments and operations.

Additionally, the level of mathematical formulations associated with the estimation of soil particle size systems can be easily handled by civil engineers or geotechnical practitioner without any in-depth mathematical abilities. Furthermore, estimations are quite accurate as evidenced from the comparisons with literature data (with average absolute deviation being less than 0.5%) and would help in attempting engineering and operations in soil mechanics calculations with less time. The proposed method has clear numerical background, wherein the relevant coefficients can be retuned quickly if more data become available in the future.

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